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Improvement of some chemical properties of an Ultisol of East Kalimantan through application of combined coal fly ash and oil palm empty fruit bunch

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Coal fly ash and oil palm empty fruit bunch are industrial wastes that enormously available in areas of East Kalimantan dominated by Ultisols with poor soil chemical properties. The objective of this study was to explore the possible improvement of soils chemical properties of an Ultisol of East Kalimantan through application of combined coal fly ash and oil palm empty fruit bunch. Twelve treatments which were combination of four doses of coal fly ash (0, 20, 40, and 80 t / ha) with three doses of oil palm empty fruit bunch compost (0, 10, and 20 t / ha) were arranged in completely randomized design with three replications. Each o combination of coal fly ash and oil palm empty fruit bunch compost was mixed evenly with soil and incubated for 10 weeks. The soil chemistry properties analyzed after 10 weeks incubation were pH, exchangeable Al, exchangeable H, total P, available P, and organic C. The results showed that there were improvements in soil chemical properties that were identified by the increase of soil pH, total P, available P. and organic C contents and of the decrease of exchangeable Al and H. Except for organic C which was only influenced by application of oil palm empty fruit bunch compost, the combination of coal fly ash and oil palm empty fruit bunch compost gave a better effect compared to application of coal fly ash without oil palm empty fruit bunch compost, or vice versa application of oil palm empty fruit bunch compost without cal fly ash. The combination of 80 t coal fly ash / ha and 20 t oil palm empty fruit bunch compost / ha increased pH by (24%), total P (101%), available P (542%) and decreased exchangeable Al (90%) and exchangeable H (53%) compared to the initial soil chemical properties.

Keywords: coal fly ash, oil palm, empty fruit bunch, chemical properties, Ultisol

INTRODUCTION

Ultisol is a type of soil found in Kalimantan, Sumatra, Papua and Sulawesi, with an area of nearly 45.8 million ha or about 25% of the land area (Sudaryono, 2009). Utilization of Ultisol for agriculture is faced by various constraints of soil chemical and physical properties. Ultisol generally has a low pH (less than 4.5), high Al saturation (can reach more than 60%) (Ohta et al., 1993), poor nutrients of K, Ca, and Mg (Ermadani and Muzar, 2011), low availability of P (Hilman et al., 2007), and low organic matter content (Prasetyo and Suriadikarta, 2006). In addition, Ultisol has a high clay content (> 70%) (Yulnafatmawita et al.,

2014) that can limit soil aeration and water retention (Prasetyo and Suriadikarta, 2006).

An attempt that has been made by farmers to improve fertility of Ultisol is by application of organic materials. Minardi et al., (2007) showed that application of *Gliricidia sepium* organic matter was able to increase available P equal to 53.61% in an acid soil. *Gliricidia* and *Tithonia* pruning composts decreased exchangeable Al concentration, increased Al-chelate levels, increased soil pH, increased available P, and increased uptake of P by crops grown on an Ultisol (Wahyudi et al., 2010; Wahyudi and Handayanto, 2015). Kasifah et al. (2014) reported that availability of P in the soil and increase P uptake by maize grown on an Ultisol of South Sulawesi could be improved optimally by application of 25 t groundnut compost/ha. However, the availability of the type of organic materials in the form of plant residues mentioned above is very limited. Therefore, it is necessary to explore other sources of organic material.

One source of organic material that is widely available in areas dominated by Ultisol is oil palm empty fruit bunch which is one form of oil palm plant biomass, in addition to stems, leaves and palm oil (Mohammad et al., 2012). Various research results indicate that oil palm empty fruit bunch compost contains 1.91-2.38% total N; 0.54% P; 1.51- 2.13% K; 0.18-0.83% Ca; 0.09-0.17% Mg; 31.01-51.23% organic C; pH 7.02-7.13; 0.59% Fe; 0.50% Na; 84.24 ppm available P; and cation exchange capacity 52.13 me / 100 g (Elfiati and Siregar, 2010; Purnamayani et al., 2012; Ichriani et al., 2017). Ariani (2009) reported that the application of 250 kg oil palm empty fruit bunch mulch / ha on chili pepper could increase 50% of chili fruit production compared to pepper plant with rice straw mulch and rice husk. Compost of oil palm empty fruit bunch can also increase the yield of dry weight of soybean seeds with compost treatment as much as 20 t / ha (Ermadani and Muzar, 2011). The results of study conducted by Budianta et al., (2010) showed that the application of 21 compost of oil palm empty fruit bunch / ha on an Ultisol from Sembawa Rubber Research Station, North Sumatra decreased Al solubility by 40.6% and Al-P fraction by 32.5%, and increased availability of P by 73.8%, P absorption by 198% and dry matter soybeans by 50% compared to control.

Ultisol productivity improvement can also be done with the application of coal fly ash generated mostly from coal combustion in Steam Power Plant, and in coal-fired industries. Coal fly ash production in Indonesia in 2006 was 1.70 million tons (Aziz et al., 2006), and in 2012 it increased to 4 million tons (Hermawan et al., 2014). Coal fly ash is defined as a fine grain of coal combustion residue results (ASTM, 1988). The ash is a mixture of particles with very complex compositions (Kurniawan et al., 2010).

In general, coal fly ash particles are spherical with size ranging from 0.5-100 µm (Kurniawan et al., 2010). The small particle size causes coal fly ash has the characteristics of water-binding capacity from medium to high, and the cement-forming properties that can inhibit the development of plant roots (Muhammad et al., 2012). The coal fly ash content consists mainly of silicate dioxide (SiO_2), aluminum (Al_2O_3), iron (Fe_2O_3), and calcium (CaO), as well as a small amount of magnesium, potassium, sodium, titanium, and sulfur (Nugraha and Antoni, 2007). Inthasan et al. (2002) reported that coal fly ash contains 17% Si, 11% Fe, 9.8% Al, 6.4% Ca, 1.4% K, 1.2% Mg, 0.4% Na, 582 ppm Mn, 53 ppm Ni, 34 ppm Co, 67 ppm Cr, and 20 ppm Mo. Based on the physical and chemical properties of the coal fly ash, coal fly ash can be used to improve the properties of acid soils to increase agricultural production. Nevertheless, the use of coal fly ash for agriculture still raises the debate. One reason is the potential risk of natural environmental pollution with heavy metals such as Cu, Ni, Cr, Zn, Cd, Mo, Se, Pb, As, Hg, and B contained in coal fly ash (Lee et al., 2006; Sharma and Karlan, 2006; Mahalen et al., 2012; Ukwattage et al., 2013).

The direct influence of solid coal fly ash on soil properties has been widely studied (Inthasan et al., 2002; Ukwattage et al., 2013; Jala and Goyal, 2006). Aggarwal et al., (2009) reported that the use of coal fly ash on soil could improve the physical and chemical properties of the soil and increased the growth and yield of wheat and sorghum. Application of coal fly ash to soils tended to reduce soil bulk density that n turn increased soil, available water, and yields of maize, sorghum and wheat crops (Sharma and Kalra, 2006). Mixing 10%, 20%, 30%, 40%, 50% and 60% coal fly ash with soil could accelerate germination of wheat crops (Mahalen et al., 2012). Wardhani et al., (2012) who conducted a study of mixing coal fly ash mixing with soil reported that the composition of 75% of soil with 25% coal fly ash, and composition of 50% soil and 50% coal fly ash resulted in accelerated growth that exceeded control of tomato plants and no toxic symptoms in the tomato plants.

The objective of this study was to explore the effect of combined application of coal fly ash and palm oil palm empty fruit bunches on the improvement of some chemical properties of an Ultisol of East Kalimantan.

MATERIALS AND METHODS

This study was conducted at Soil Laboratory of Faculty of Agriculture Brawijaya University from November 2016 to February 2017. The incubation experiment in laboratory was done under non-leaching condition following the method used by Handayanto et al. (1994). The materials used in this study were Ultisol soil, coal fly ash, and compost of oil palm empty fruit bunches.

Ultisol soil used in this study was collected from farmers' land in Mangkurawang Village, Tenggarong Subdistrict, Kutai Kartanegara Regency, East Kalimantan Province. Characteristics of Ultisol top soil (0-20 cm) used in the study were as follows: clay texture (25% sand, 49% silt, 26% clay), water available content 13.87%, pH (H_2O) 4.1, organic-C 1.23 %, total-N 0.14%, total-P 37.22 ppm, available P 3.76 ppm, exchangeable cations of Ca, Mg, K, Na, Al and H, respectively 3.17, 1.08, 0.12, 0.13, 4.45, and 1.08 cmol/kg, cation exchange capacity 21.18 cmol / kg, and base saturation 44.87%.

Coal fly ash was obtained from Steam Power Plant of PT. Cahaya Fajar Kaltim in Embalut Village, Tenggarong Seberang Subdistrict, Kutai Kartanegara Regency, East Kalimantan Province. The characteristics of ATB are as follows: silt texture (9% sand, 90% silt, 1% clay), water available content 18.86%, pH (H_2O) 9.8, organic-C 0.82%, total-N 0.05%, total-P 1.378 ppm, available P 5.73 ppm, total-K 719.35 ppm, exchangeable cations of Ca, Mg, K, Na, and H 28.45, 3.25, 0.25, 0.26, and 0.08 cmol / kg respectively, cation exchange capacity 17.37 cmol / kg, and base saturation 99.75%. Compost of oil palm empty fruit bunches was obtained from PT. Surya Inti Sawit Kahuripan (Makin Group), Parenggean District, Kotawaringin Timur, Central Kalimantan Province. The characteristics of oil palm empty fruit bunches are as follows: pH (H_2O) 6.7, organic-C 17.30%, total-N 1.56%, total-P 3700 ppm, total K 1100 ppm, exchangeable cations of Ca, Mg, K, and Na, respectively 3.49, 1.21, 0.52, and 0.82 cmol / kg. The experimental treatments were combinations of four doses of coal fly ash (0, 20, 40, and 80 t / ha) with three doses of oil palm empty fruit bunch compost (0, 10, and 20 t / ha). Twelve treatments were arranged in a completely randomized design with three replications. Each treatment combination of coal fly ash-oil palm empty fruit bunch compost was mixed evenly with 400 g of soil (top soil of Ultisol, diameter <2 mm, air dried), and placed in a plastic pot of 500 g and then water was added to 80% of field capacity. All pots were covered by aluminium foil with two or three small holes to reduce evaporation but still had aeration. All pots were placed indoors at temperature of $\pm 26^0$C. During the incubation period the moisture content was maintained to 80% of the field capacity by periodically weighing the pots. At 10 weeks, observations were made for pH (H_2O 1: 1 with pH meters), total-P (method of Olsen and Sommers, 1982), available-P (method of Bray and Kurtz, 1945), organic-C (method of Walkley and Black, 1934), exchangeable Al and H (method of Rayment and Higginson, 1992). The data obtained were analyzed using analysis of variance followed by Least Significant Different test at 5% level.

RESULTSAND DISCUSSION

Soil pH, and exchangeable Al and H

Application of coal fly ash and oil palm empty fruit bunch compost increased soil pH compared to initial pH (4.1). In the treatments of coal fly ash without oil palm empty fruit bunch compost, soil pH increased with increasing coal fly ash dosage (Figure 1). The amount of exchangeable Al and H decreased with increasing coal fly ash dosage (Figures 2 and 3). The addition of oil palm empty fruit bunch compost to the coal fly ash and soil mixture increased the soil pH and decreased the amount of exchangeable Al and H, which is in line with the increased dosage of oil palm empty fruit bunch compost. The highest increase of pH (24%) occurred in treatment of A80K20, from 4.1 to 5.1 (Figure 1). Ciećko et al., (2015) reported that coal fly ash used as a soil amendment with doses between 200-800 t / ha increased soil pH and soil P availability. Coal fly ash generally contains high amounts of silicate minerals such as mullet (Ram et al., 1995), which can bind H^+, which then causes neutralization through the formation of silicic acid. Thus, the dissolution of small amounts of silicate minerals may increase soil pH. According to Priatmadi et al., (2014), the addition of coal fly ash increased the negative charge of the soil through the mechanism of deprotonization of H^+ ions in clay minerals. The occurrence of deprotonization of H^+ ions is indicated by an increase in soil pH with the addition of coal fly ash. Deprotonination of H^+ causes a decrease in the amount of exchangeable H^+ (Figure 3).

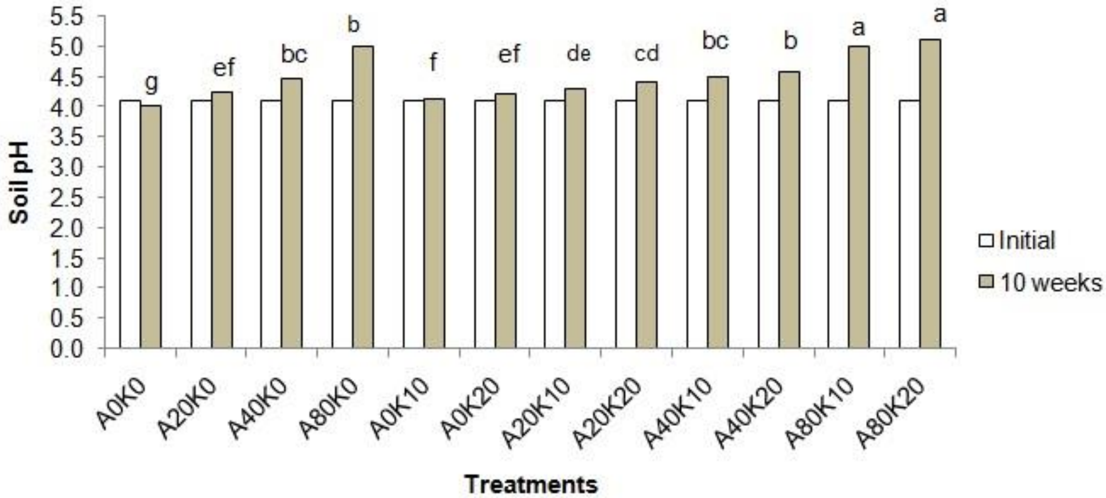

Figure 1. Effect of application of combined coal fly ash and oil palm empty fruit bunch compost on pH of an Ultisol of East Kalimantan. Remarks: A = coal fly ash; K = oil palm empty fruit bunch compost; 0, 10, 20,40, 80 = dose of coal fly ash or oil palm empty fruit bunch compost in t / ha

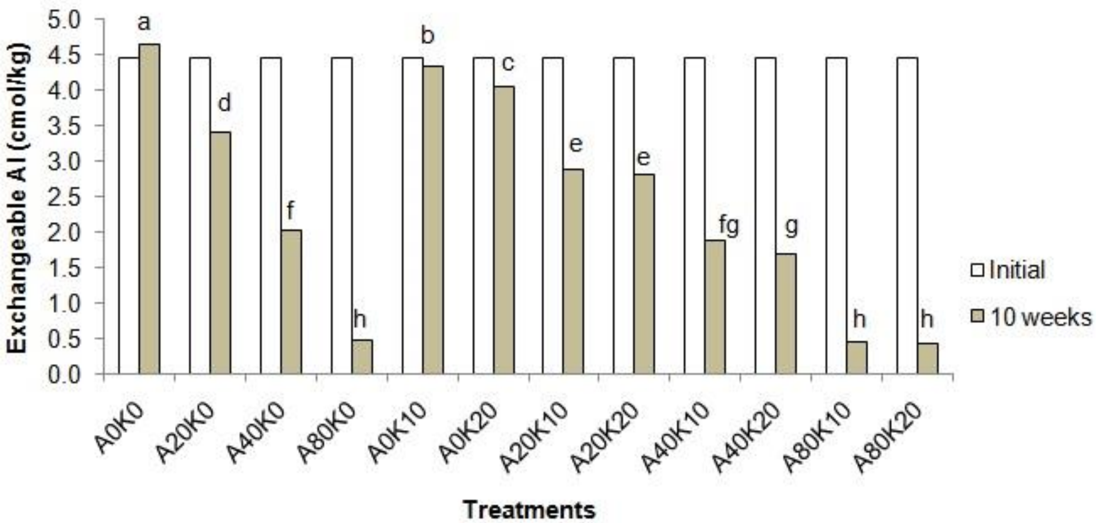

Figure 2. Effect of application of combined coal fly ash and oil palm empty fruit bunch compost on exchangeable Al of an Ultisol of East Kalimantan. Remarks: A = coal fly ash; K = oil palm empty fruit bunch compost; 0, 10, 20,40, 80 = dose of coal fly ash or oil palm empty fruit bunch compost in t / ha

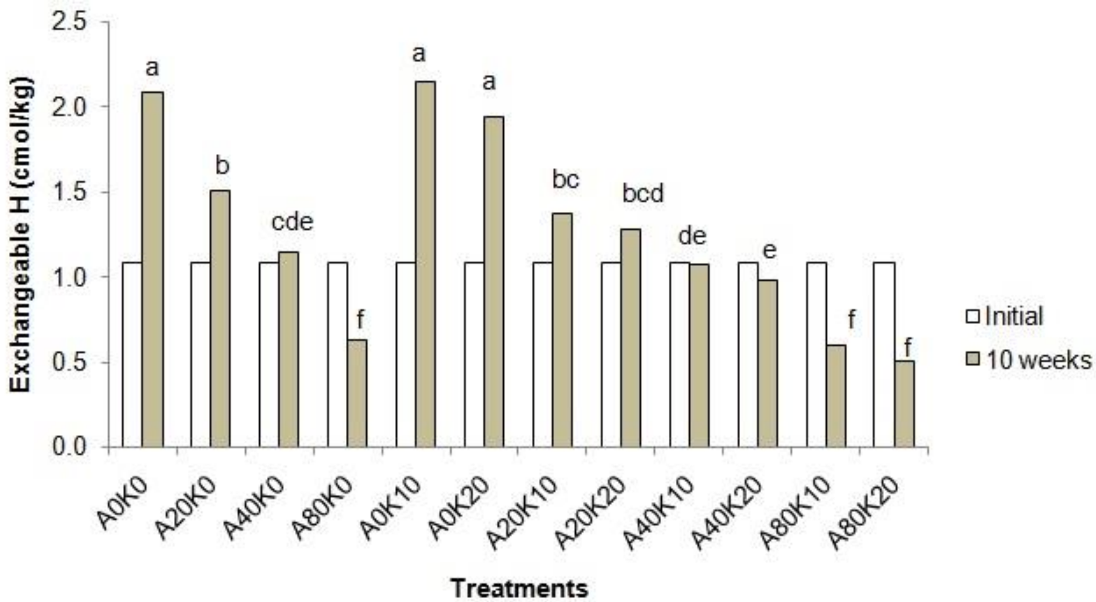

Figure 3. Effect of application of combined coal fly ash and oil palm empty fruit bunch compost on exchangeable H of an Ultisol of East Kalimantan. Remarks: A = coal fly ash; K = oil palm empty fruit bunch compost; 0, 10, 20,40, 80 = dose of coal fly ash or oil palm empty fruit bunch compost int/ha

Compared with the initial exchangeable Al content, the combined application of coal fly bash and oil palm empty fruit bunch compost decreased the exchangeable Al content between 3% (A0K10 treatment) to 90% (A80K20 treatment) (Figure 2).The increase in soil pH as a result of the addition of coal fly ash as a soil amendment occurs due to the release of Ca, Na, Al and OH^- from coal fly ash (Wong and Wong 1986). Because coal fly ash contains hydroxide and carbonate salts, coal fly ash has the ability to neutralize soil acidity (Pathan et al., 2003). This pH change of the soil-coal fly ash-compos mixture is thought to be related to the process of decomposition of organic matter in the mixture. Increasing the decomposition process of organic matter can cause the decrease of pH among others by the release of CO_2 from the respiration process of microorganisms that can react with H^+ ion to form weak acid (H_2CO_3) and also through nitrification process that produces H^+ (Tan, 2003). Farrell et al., (2010) state that compost applications increase the content of Ca^{2+} in soil solution. The increase of Ca^{2+} ions in soil solution will be able to replace Al^{3+} and H^+ and bind Al^{3+} to an insoluble Al^{3+} complex, so the soil pH increases that in turn increasing the availability of P in the soil.

Total-P, available-P, and organic-C

Application of coal fly ash with high pH (9.8) and oil palm empty fruit bunch compost with neutral pH (6.7) to soil with low pH (4.1) caused the pH of soil-coal fly ash-compost mixture to be optimal for the process of total P decomposition in coal fly ash and oil palm empty fruit bunch compost to become available P (Jala and Goyal, 2006). The application of coal fly ash and oil palm empty fruit bunch compost in the soil studied increased the amount of soil available P (4-24%) and soil total P (13-101%), compared to the initial content of available P in the soil (3.76 ppm) (Figure 4). The amount of total-P at treatments of A0K0, A20K0, and A0K10 actually decreased by 1-3% but the decrease was not significant. All treatments had significant effect on control (A0K0). In the treatment of 20, 40, and 80 t coal fly ash / ha without applications of oil palm empty fruit bunch compost, the amount of soil available P increased with increasing rate of coal fly ash applied (Figure 4).In the application of 10 t oil palm empty fruit bunch compost / ha without coal fly ash, the amount of soil available P was higher than the that of the control treatment but lower than the treatment of 20 t coal fly ash / ha without the addition of oil palm empty fruit bunch compost (A20K0). This indicates the important role of coal fly ash in supplying availability of P even without the addition of oil palm empty fruit bunch compost.

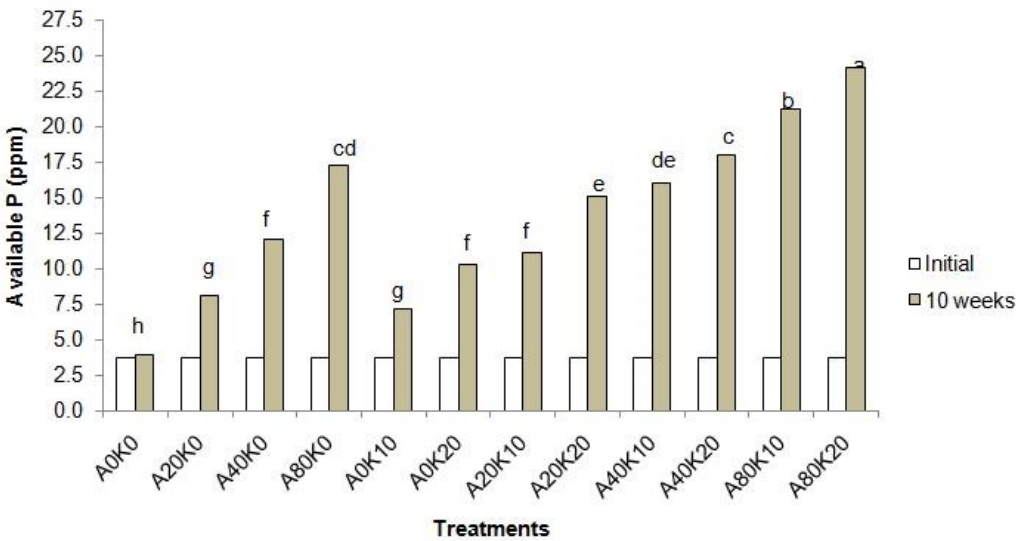

Figure 4. Effect of application of combined coal fly ash and oil palm empty fruit bunch compost on available P of an Ultisol of East Kalimantan. Remarks: A = coal fly ash; K = oil palm empty fruit bunch compost; 0, 10, 20,40, 80 = dose of coal fly ash or oil palm empty fruit bunch compost in t / ha

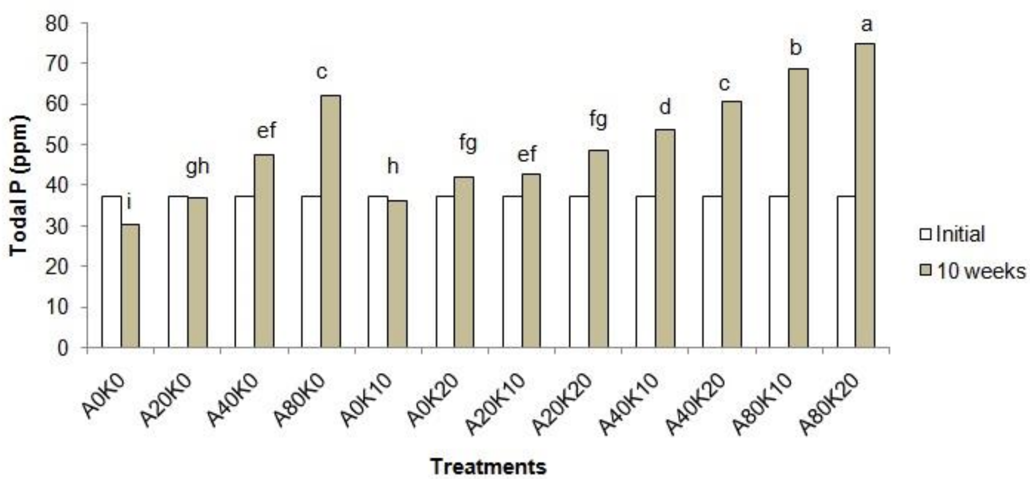

Figure 5.Effect of application of combined coal fly ash and oil palm empty fruit bunch compost on total-P of an Ultisol of East Kalimantan. Remarks: A = coal fly ash; K = oil palm empty fruit bunch compost; 0, 10, 20,40, 80 = dose of coal fly ash or oil palm empty fruit bunch compost in t / ha.

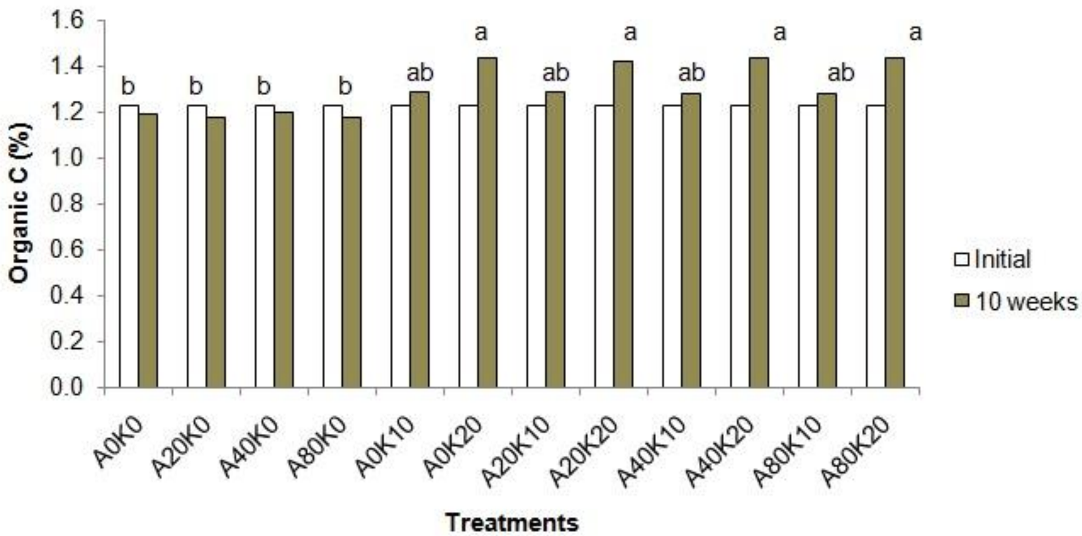

Figure 6. Effect of application of combined coal fly ash and oil palm empty fruit bunch compost on organic-C of an Ultisol of East Kalimantan. Remarks: A = coal fly ash; K = oil palm empty fruit bunch compost; 0, 10, 20,40, 80 = dose of coal fly ash or oil palm empty fruit bunch compost in t / ha

However, in other treatments, the addition of oil palm empty fruit bunch compost (10 and 20 t / ha) combined with 20, 40, and 80 t coal fly ash / ha further increased the amount of soil available P compared to without the addition of oil palm empty fruit bunch compost. Application of 80 t coal fly ash / ha without oil palm empty fruit bunch compost increased the content of soil available P by 361% compared to the initial available P content of 3.76 ppm and the control treatment (Figure 4). If treated with oil palm empty fruit bunch compost of 20 t / ha resulted in an increase of P of 542%. This improvement is consistent with the results of Pathan et al. (2003) that at least 2.5-4.5 times the increase in the content of extracted P due to the addition of coal fly ash, compared to the control (without the addition of coal fly ash).

In addition to increasing the available P content, application of coal fly ash and oil palm empty fruit bunch compost also increased the total P content after 10 weeks. Compared with the initial P-content (37.22 ppm), except treatments of A0K0, A20K0, and A0K10, all treatments experienced an increase in total P content ranging from 13% in A0K20 treatment to 101 % in A80K20 treatment (Figure 5).The increase in the amount of available soil P might not be caused by the supply of available P from coal fly ash because the content of available P in coal fly ash is low (5.73 ppm). The increase of available P was probably due to the high content of total P in coal fly ash (1738 ppm) and oil palm empty fruit bunch compost (3700 ppm). Hermawan et al. (2014) reported that chicken manure and coal fly ash mixtures can be used as ameliorants to reduce adsorbed P and increase P availability in Ultisol soil by increasing pH and soil negative charges. Coal fly ash can improve fertility of acid and degraded soils for the following reasons: coal fly ash increases the available surface area of elemental traction, improves soil physical properties (Gorman et al., 2000), mineralizes pH of acid soil, and produces metal cations to be less mobile (Ciccu et al., 2003). In addition, coal fly ash contains K and elemental bases (Ca, Mg) which are essential nutrients for plants. Mixing of coal fly ash with organic matter on acid soils is expected to stimulate biological activity in the soil (Jala and Goyal, 2006), reduce nutrient leaching (Sajwan et al., 2003) and benefit to plants (Rautaray et al., 2003; Tripathi et al., 2009). Rani and Kalpana (2010) also reported that application of coal fly ash to soil increase the availability of nutrients such as nitrogen, phosphorus, and other micro-nutrients. Das et al. (2013) reported that application of coal fly ash with doses of 5 t / ha, 10 t / ha and 15 t / ha increased available P content in soil. The increase of P_2O_5 content due to coal fly ash application is also reported by Lee et al. (2006).The beneficial effect of coal fly ash on the availability of P is expressed as its effect on biotic activity and release of P through biotic activity. The existing Si element in coal fly ash also plays an important role in the release of P becoming available from insoluble sources in coal fly ash and soil (Lee et al., 2006). Im-Erb et al., (2004) who conducted a study of the effect of coal fly ash on soil chemical properties also stated that coal fly ash application increased soil pH compared with control. According to Khan and Khan (1996), the increase of coal fly ash concentration in normal soil from 0, 10, 20 to 100% volume / volume increased pH, which in turn increased the availability of sulphate, carbonate, bicarbonate, chloride, P, K, Ca, Mg , Mn, Cu, Zn and B. The increase in soil available P content was also probably due to available P and organic P from oil palm empty fruit bunch compost. The content of available P in the mixtures of coal fly ash and oil palm empty fruit bunch compost that tended to increase with increasing proportion of oil palm empty fruit bunch compost in the mixtures showed that the main source of P in the mixture came from oil palm empty fruit bunch compost. Data presented in Figure 6 show that application of 20 t oil palm empty fruit bunch compost / ha increased the organic C content significantly compared t the control. The Increase of organic C content due to application of oil palm empty fruit bunch compost because organic C content of the compost is very high (17.30%). In contrast to oil palm empty fruit bunch comport, application of coal fly ash up to 80 t / ha did not have a significant effect on organic C content compared to the control. This is because the organic C content in coal fly ash is very low (0.82%). In other words, the increase of organic C content in the soil studied was caused by the application of oil palm empty fruit bunch compost.

CONCLUSION

Application of combined coal fly ash and oil palm empty fruit bunch compost increased pH, available P, total P and organic C but decreased exchangeable Al and H of an Ultisol from East Kalimantan. The combination of coal fly ash and oil palm empty fruit bunch compost resulted in a higher pH and decrease in exchangeable Al and H compared to application of coal fly ash alone or applications of oil palm empty fruit bunch compost alone. The combined application of 80 t coal fly ash / ha and 20 t oil palm empty fruit bunch compost / ha resulted in the highest increase of pH of 24% and vice versa resulted in the largest decrease of exchangeable Al and H, respectively 90% and 53% compared to the initial soil. The application of 80 t coal fly ash / ha together with 20 t of oil palm empty fruit bunch compost / ha resulted in the highest total P content (74.99 ppm) of 101% increase compared to the initial soil total P and the highest available P (24.14 ppm) or 542% increase compared to the initial soil available P.

CONFLICT OF INTEREST

The authors declared that the present study was performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

FR and EH designed and performed the experiments and also wrote the manuscript. ZK and BP reviewed the manuscript. All authors read and approved the final version..

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